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Comparative Studies on Strength Characteristics of Microbial Cement Mortars

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Abstract: Microbially induced calcium carbonate precipitation (MICCP) is a novel method for the protection of cement-based materials. This paper deals the comparative studies on strength characteristics in microbial cement mortars which were treated by *Enterobacter sp. M2* microorganism in different calcium source (calcium hydroxide, calcium acetate, calcium chloride and calcium oxide) with various curing process. The crystalline phases of calcium carbonate ($CaCO_3$) crystals formation and the surface morphology of cement mortar were investigated by X-ray diffraction (XRD) and scanning electron microscope (SEM). Cement mortar specimens with and without addition of bacterial species were casted and ~ 44% increase in compressive strength, ~56% in tensile strength was noticed while compared to control specimen (without bacteria). Surface treatment of specimen with bacteria resulted around ~40% decrease of water absorption and increases the resistance to water and hazard material penetration, mainly attributed to its pore blocking effects. This biological surface treatment shows promising prospect for increasing durability aspects of concrete/cement mortar.
Keywords: Calcium carbonate, Compressive strength, Tensile strength, Sorptivity, MICCP.

Introduction

Microbial calcium carbonate precipitation in a cement mortar/concrete is a complex mechanism. In nature the $CaCO_3$ precipitation is accompanied by biological process. Based on continuous research a number of innovations have been made from time to time to improve the strength and durability performance [1] of cement mortar/concrete. Bacterially induced $CaCO_3$ and mediated mineralization is a research subject which was

widely studied in the past decade [2-4]. Use of microorganism with in cement mortar/concrete leading to the process of bio mineralization is a potential field of research in concrete technology [5,6]. Abundant significance of microbially induced calcium carbonate precipitation (MICCP) so called carbonatogenesis has put much awareness from both basic and applied point of view in civil engineering field [7]. The $CaCO_3$ precipitation is a function of ionic strength and pH in the medium [8]. The increase of compressive strength of mortar is due to complex interaction between the bacterium and cement matrix [6].

The presence of MICCP in the cement mortar through XRD and scanning electron microscope (SEM) had been analyzed and reported [9] that the crystallization of $CaCO_3$ as vaterite (V), aragonite (A), calcite (C). Even though the cement mortar/concrete is relatively strong mechanically, but it suffers by low tensile strength, permeability to liquid and consequent corrosion of reinforcement, susceptibility to chemical attack and low durability. The cement mortar/concrete is not usually expected to resist the direct tension because of its low tensile strength and brittle nature. However, the determination of tensile strength of cement mortar/concrete is necessary to determine the load at which the cement mortar/concrete members might crack. The presences of MICCP in cement mortar/concrete affect the compressive strength and indirect split tensile strength [10-14]. The increased compressive strength and split tensile strength was noticed while varying the cell concentration [15]. The bio deposition treatment resulted in an increased resistance of mortar specimens towards carbonation, chloride infiltration and freezing–defrosting [16-18].

The durability and life of cement mortar/concrete specimens is estimated by the capillary water movements into it. Higher absorption of water by the specimen would imply higher damage and vice versa. The influence of microbial cement mortar/concrete on penetration properties had been studied and analyzed [10,19]. The bacterial treated specimens were found to have better resistance towards chloride penetration as compared to control specimens [20]. A decreased water permeability of bioremediated cement mortar cubes treated by *Sporosarcina pasteurii* bacteria was reported [10] along with six times reduction in absorption of water upon treatment of mortar cubes with *Bacillus* sp. CT-5 as compared to control specimens. Some other factors like, initial moisture content or saturation [21], compaction [22] and curing time [23] were mostly influencing capillary water transport. Weight loss, reduction in compressive strength, and change in dynamic modulus of elasticity are used to evaluate the extent of cement mortar/concrete deterioration due to acid attack.

A successful attempt has been made on the biomineralization process to enhance the compressive strength, indirect split tensile strength and durability of cement mortar/concrete by using the *Enterobacter sp. M2* (EB) microorganism in different calcium source and curing process. The present work deals with the measurement and comparison of compressive strength, indirect split tensile strength, acid attack and water permeation properties of the cement mortars.

Experimental

Ordinary Portland Pozzolana Cement conforming to IS 1489:1991 with specific gravity of 3.1 was used to prepare the cement mortar specimens. Locally available clean river sand conforming to IS 650:1991 with specific gravity 2.7 and fineness modulus 2.96 was used as fine aggregate. The microorganism (EB) was collected from Central Electrochemical Research Institute, Karaikudi, Tamilnadu which were isolated from cooling water towers for bacterial treatment. B4 broth medium was prepared from 0.5% yeast extract, 0.5% glucose and 1% calcium acetate solution and EB is added. Then the solution was shacked at 30° C (using orbital Shaker) for 3 days with 150 rpm to grow and multiply the bacterial species (EB). After the centrifugation the supernatant was extended to the optical density (600nm) of 1 in UV/ VIS Spectrometer. Then 3ml of EB was added with B4 broth medium then it was mixed with different bacterial culture grown sources which contains 8g nutrient broth, 2% Urea with different calcium sources of 25mM calcium hydroxide ($Ca(OH)_2$), calcium acetate ($Ca(CH_3COO)_2$), calcium chloride ($CaCl_2$) and calcium oxide (CaO) respectively (represented as $BCGS_1$, $BCGS_2$, $BCGS_3$ and $BCGS_4$).These calcium sources were kept separately for 3 to 5 days to observe the variation of pH value.

To carry out testing procedure, each cement mortar specimens were cast with 70.6 X 70.6 X 70.6mm size by using 98.7ml of $BCGS_1$, $BCGS_2$, $BCGS_3$ and $BCGS_4$ along with 210g cement, 630g river sand by cement to sand ratio of 1:3 (by weight) and water to cement ratio 0.47 respectively as per IS 4031 – 1988. Similarly each cement mortar specimens without bacterial species (using plain calcium sources without EB) was cast for control specimen with above specification. Initially cement and sand was thoroughly mixed (dry mix), then different bacterial cultural grown sources was added into mixture separately to obtain cement mortar paste. Each cube was prepared by filling the mortar in an empty mold by 3 layers with compacted in 25 blows. In normal curing, potable water is used for mixing and curing the microbial cement mortar specimen. In bio curing, different bacterial culture growth sources (BCGS) along with EB microorganism is used for mixing and curing the microbial cement mortar specimen (i.e. the microbial cement mortar specimen is immersed into bio solution of BCGM along with EB or SB).

To analyze the compressive strength of normal and bio curing specimens, they were individually tested by using Computerized Universal Testing Machine (CUTM). The cube specimens were placed in the machine such that the load is applied to the opposite sides (not to the top and bottom). The axis of the specimen was carefully aligned with the centre of the thrust of the spherically seated platen without any backing materials in between specimen and steel platen of the testing machine. Then the load was applied gradually without shock at the rate of 140kg/cm^2/min until the resistance of the specimen to the increasing load breaks down. The maximum given load to the specimen was recorded. The test was repeated with regular intervals (7, 14, 21 and 28 days) and experimentally recorded compressive strength in different curing process of the cubic specimen was tabulated.

The splitting tests are well known indirect tests used to determine the tensile strength of cement mortar/ concrete.

The specimen cylinder (50mm diameter and 100mm length) were prepared from the mixture of cement to sand ratio 1:3 (by weight) and water to cement ratio 0.47 as per IS 4031 – 1988 along with three layers, each having 25 blows. The test consisted of applying a compressive line load along the opposite generators of a specimen placed with its axis horizontal between the compressive platens. To prevent multiple cracking and crushing at the points of load applied, the load was distributed through two bearing strips whose width is b (b=30mm).

To calculate the sorptivity coefficient the different normal, bio cured specimens (50mm diameter and 100mm length of cylinder) were dried at 100°C in a ventilated oven after curing of 28 days. Then the specimens were coated with two layers of water proof resin of ISO 0081 at all outer surfaces except top and bottom of the cylindrical specimen to ensure unidirectional absorption through the non treated side. The specimens were submerged to 5mm of water with the non treated side facing downward while the water level approximately 2 mm above the base of the specimen. At regular time intervals (15 min, 30 min; 1 h, 1.5 h, 3 h, 5 h, 8 h, 24 h, 72 h, 96 h, 120 h, 144 h, and 168 h), the specimens were removed from the water and weighed after drying the surface with a wet towel. Immediately after the measurement, the test specimens were sunken again to continue the observation to obtain saturated value of water infiltration.

Instrumentations

Optical density of the B4 broth medium was analyzed by using Lambda 35 UV/VIS spectrometer (Perkin Elmer- USA). The sophisticated instruments like, Forma orbital Shaker (model: 420, S.No:13500-1712), Thermo Electron Corporation (Hong Kong) LTD and Computerized Universal Testing Machine (CUTM) with capacity of 1000kN, accuracy of 0.1kN, Fine Spray Associates & Engineering PVT. Ltd, Maharashtra, India was used to grow the microorganism and to analysis the compressive strength of cement mortar cubes respectively. Micro structure of the specimen (formation of calcium carbonate) was analyzed with high resolution (3.0 nm-30kV) JSM-6390 Scanning Electron Microscope (SEM), USA with magnification of 5 to 300,000. The elemental analysis was carried out with XRD 6000 Shimadzu- Japan. Water absorption in specimen was experimentally analyzed and the results are discussed.

Microorganism and its Activity

The key point of the present study is to select the suitable microorganism (bacterial species) and incorporate into cement mortar for its efficient activation. Possible biochemical reaction in the medium (Stocks-Fischer *et al*., 1999) such as urease catalyzed hydrolysis of urea to precipitate $CaCO_3$ at a cell surface that provides a nucleation site is given below:

$$CO(NH_2)_2 + H_2O \xrightarrow{\text{Urease}} NH_2COOH + NH_3 \quad (1)$$

$$NH_2COOH + H_2O \longrightarrow NH_3 + H_2CO_3 \quad (2)$$

$$2NH_3 + 2H_2O \rightleftharpoons 2NH_4^+ + 2OH^- \quad (3)$$

$$2OH^- + H_2CO_3 \rightleftharpoons CO_3^{2-} + 2H_2O \quad (4)$$

$$Ca^{2+} + CO_3^{2-} \longrightarrow CaCO_3 \quad (5)$$

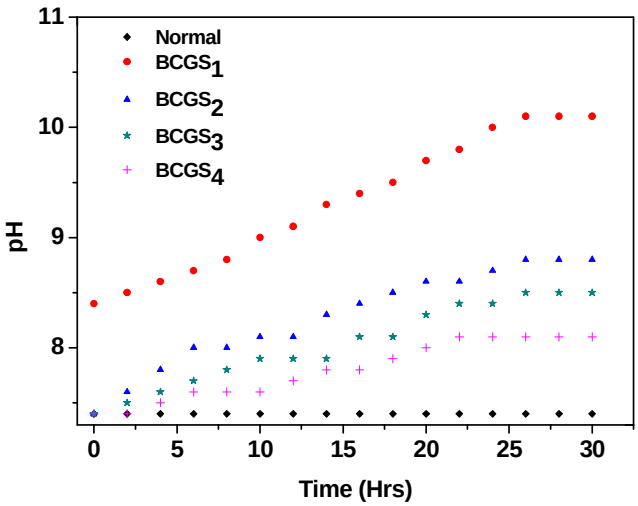
As a result $CaCO_3$ particles were precipitated gradually between cement sand matrix and on the surface of the specimen.

Results and Discussion

Variation of pH and microbial activity

Urease catalyzed hydrolysis of urea to precipitate $CaCO_3$ at a cell surface was prepared from various calcium sources. The pH value increases from 7.4 to 10.1 (within 30 hrs) in different calcium sources which confirm the presence of bacterial activity. The observed result is compared with earlier reported data and the graph is drawn (as shown in figure 1). The pH value is unaltered even when time duration increases from 0 to 30hrs in the bacterial culture growth solution in the absence of microorganism. As time increases, the pH also increases in the $BCGS_1$, $BCGS_2$, $BCGS_3$ and $BCGS_4$ as shown in the figure 1. Due to the enrichment activity of bio chemical reaction by the EB microbial bacteria in calcium hydroxide source, a large difference of pH value is noticed in between BCGS and $BCGS_1$.

Figure 1. Variation of pH with time in different calcium sources of bacterial species



Microbially Induced Calcium Carbonate Precipitation (MICCP)

MICCP in the samples are examined through SEM and the images from various samples are shown in figure 2 and 3. Due to many pores in the cement mortar specimen, from the figure 2 very minute white $CaCO_3$ precipitation is observed in the bacteria free cement mortar (control) specimen. During initial curing period of microbial cement mortar, the microbial cell get good nutrient from the different curing solution (BCGS). So the bacterial cells initially grow slowly and adjusted to high pH conditions during curing period. During cell growth, calcite is precipitated on the cell surface and within cement mortar matrix. Urea and calcium irons on the surface of the cement mortar specimens, which created a micro-environment for the growth of the micro-organism; thus calcite particles were precipitated on the local surface directly and gradually instead of in the liquid culture. Due to significant microbial activity of EB in the production of $CaCO_3$, a clear deposition of white calcium carbonate precipitation on the surface is identified in the bio curing $BCGS_1$cement mortar specimen as shown in figure 3. Also calcium carbonate particles are uniform in size and cemented to each other more tightly giving evident protection to the surface of the $BCGS_1$ microbial cement mortar specimen. This enriched MICCP is one of the substantiation to increase compressive strength in the bio curing $BCGS_1$cement mortar specimen.

Comparison of XRD patterns among various treatments

An XRD analysis was employed to determine the crystalline form of the crystals. For that each samples were crushed to an average particle size of less than 10 microns and then the mass absorption coefficient was determined by X-ray transmission. The XRD pattern was obtained (figure 4) by scanning sample by 2θ value is 5 to 90 degree. The components of each sample were identified by comparing them with standards established by the International center for diffraction data. The quantitative analysis of the control and EB treated specimen ($BCGS_1$) shows that the induced crystallization characteristics peaks [vaterite (V), aragonite (A), calcite (C)] of calcium carbonate at 2θ value is around 26^o, 27^o, 28^o, 36^o, 39^o and 42^o. Due to natural existence of minerals in the control specimen there will be lesser intensity of vaterite peaks only observed at $2\theta = 21.1^o$, 27.1^o . The bio cured $BCGS_1$ specimen (figure 4) shows high intensity peaks for calcite ($2\theta = 36.7^o$, 39.6^o, 42.6^o), aragonite ($2\theta = 26.8^o$) vaterite ($2\theta = 21.0^o$, 24.5^o, 27.3^o). Among the four samples, EB treated cement mortar specimen shows high intensity peaks compared to rest of three samples, which indicates significant microbial activity to induce $CaCO_3$ in the cement mortar specimen ($BCGS_1$).

Figure 2. Bacteria free cement mortar SEM image

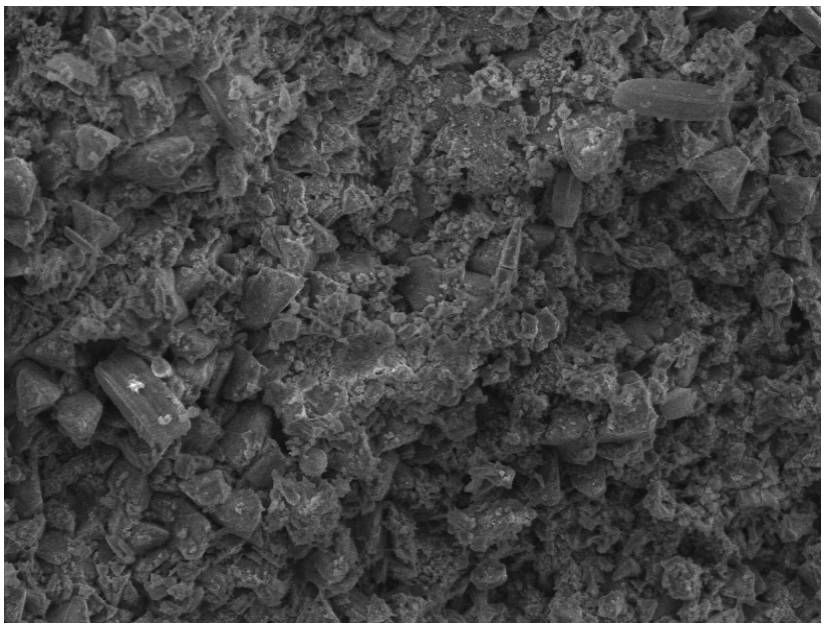


Figure 3. SEM image of $BCGS_1$

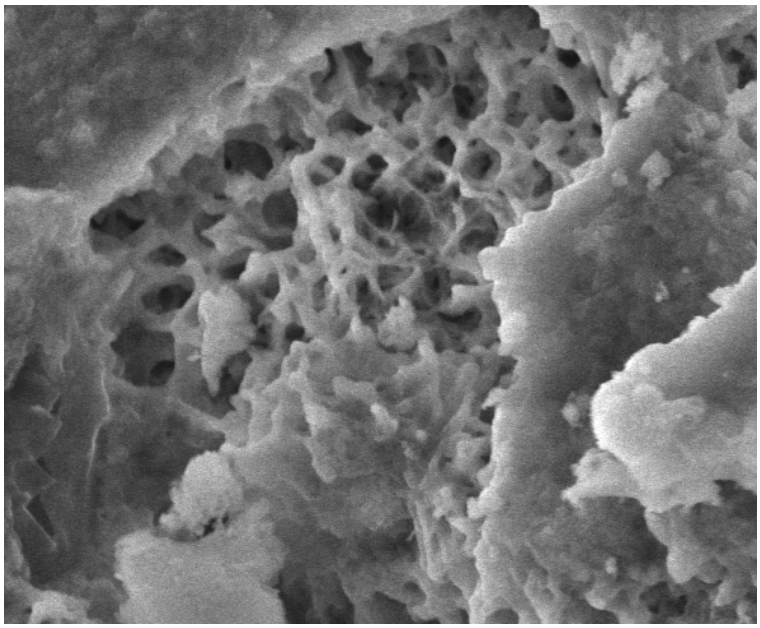
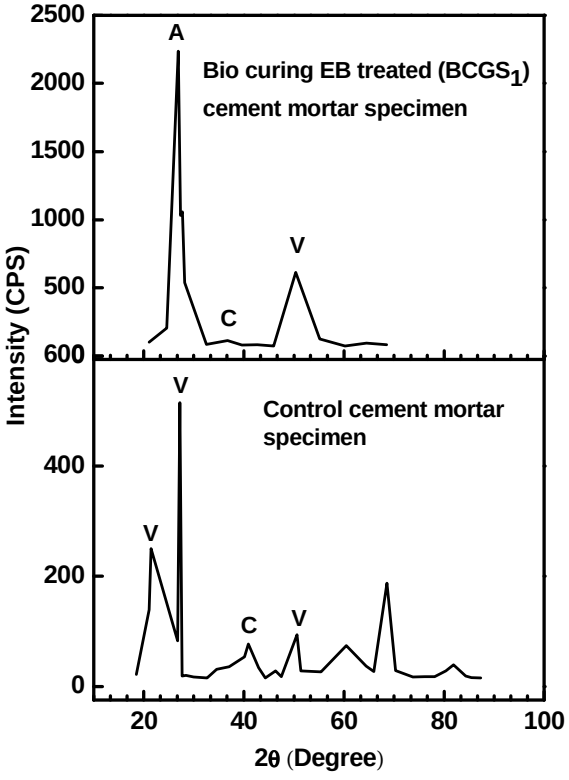


Figure 4. X-ray diffraction pattern of Control and $BCGS_1$ treated specimen



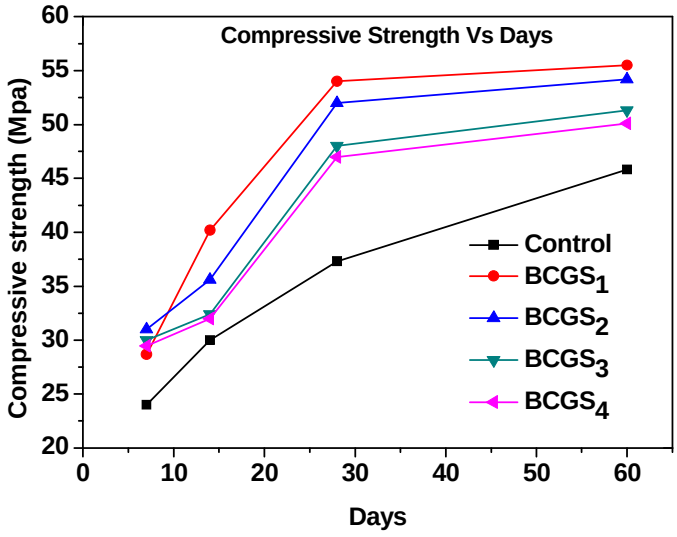
Measurement of Compressive Strength

Experimentally calculated value for compressive strength (load/area) in control specimen, normal and bio curing EB treated specimens are given in table 1.The enhanced compressive strength percentage of microbial cement mortar specimen is compared with the control specimen and the calculated values are given in table 1. From the observed data the graph is drawn between time (x-axis) and compressive strength (y-axis). As the duration of the time is increased the compressive strength also is increased and reaches saturation value around 28 days as shown in figure 5. Normal curing microbial cement mortar shows less compressive strength even at the age of 28 days. But enhanced compressive strength 44.8% is noticed in bio curing $BCGS_1$ cement mortar than control cement mortar specimen. This enhanced variation in compressive strength confirms the chemically produced urease in the form of $CaCO_3$ precipitation between cement and sand matrixes of the cement mortar specimen by the *Enterobacter* microorganism. Because of persistence of nutrition in bio curing process, the microbial cement mortar specimen shows higher compressive strength than normal curing cement mortar specimens. Also noticeable increasing compressive strength is observed in bio curing $BCGS_2$, $BCGS_3$ and $BCGS_4$ as 39.41%, 36.00% and 26.01% respectively (table 1). Due to the poor activity of EB in other calcium sources like, $BCGS_2$, $BCGS_3$ and $BCGS_4$ there is decrease in pH value which in turn reduces the $CaCO_3$ precipitation and this finally reduces the compressive strength of EB treated microbial cement mortar specimen.

Table 1. Mix identification and variation of compressive strength of control and different types of calcium sources treated cement mortar cubes with different ages.

S No	Mix id	Compressive Strength in N/mm^2				Percentage increase of Compressive Strength with respect to Medium
		7	14	28	60	28
		Days				
1	Control	24.00	30.00	37.30	45.81	-
2	$BCGS_1$	28.67	40.20	54.00	55.50	44.80
3	$BCGS_2$	31.00	35.60	52.00	54.20	39.41
4	$BCGS_3$	30.00	32.40	48.00	51.30	36.00
5	$BCGS_4$	29.47	32.00	47.00	50.10	26.01

Figure 5. Variation of compressive strength of control and different types of calcium sources treated cement mortar cubes with different ages



Indirect Split Tensile Strength

If the material behavior is linear-elastic, this geometry leads to a nearly uniform tensile stress along the plane of loading, and the expected rupture mode is the splitting of the specimen in two halves across that plane. The tensile strength is calculated from the formula as given below (IS: 5816-1970):

$$\sigma_{Max} = 2P/\Pi DL \qquad (6)$$

where, P- is the maximum applied load to the specimen, D- is the diameter of the specimen, L- is the length of the specimen. The EB treated cement mortar specimens in various calcium sources are (3 specimens in each source) are tested by using CUTM and calculated average indirect split tensile strength is given in table 2. It can be observed that the indirect split tensile strength is increasing in the bio cured specimen compared to control one. In 60 days, bio cured $BCGS_1$ specimen shows inevitable increment in split tensile strength as compared to the other bio cured EB specimens. A graph is plotted (figure 6) between time (X-axis) and indirect split tensile strength (Y-axis). In $BCGS_1$ specimen around 56% of increased split tensile strength is noticed than control specimen. Due to the significant activity of EB species in the $BCGS_1$ specimen, bio chemically induced calcium carbonate precipitation between cement sand matrixes which intern increase the load resisting capacity.

Table 2. Mix identification and variation of tensile strength of control and different types of calcium sources treated cement mortar specimens with different ages.

S No	Mix id	Indirect Split Tensile Strength in N/mm^2				% increase Indirect Split Tensile Strength with respect to Medium
		7	14	28	60	60
		In days				
1	Control	2.55	6.11	9.40	10.10	-
2	$BCGS_1$	4.30	8.00	10.50	15.80	56.44
3	$BCGS_2$	4.22	7.63	10.18	14.60	44.55
4	$BCGS_3$	3.80	6.40	9.70	12.50	23.76
5	$BCGS_4$	2.70	6.30	9.60	10.24	1.38

Figure 6. Variation of tensile strength of control and different types of calcium sources treated cement mortar specimens with different ages

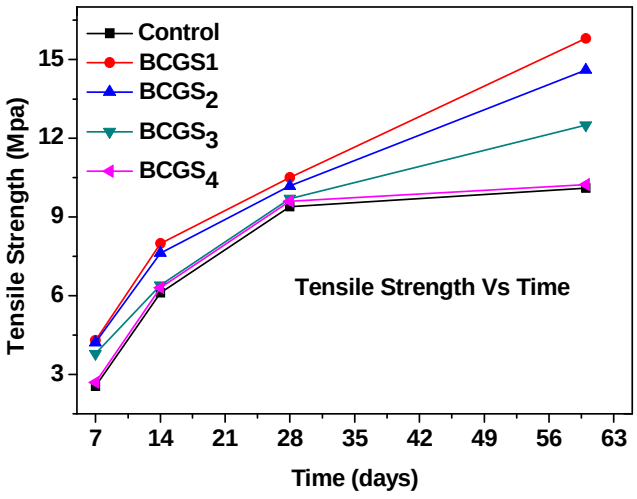


Table 3. Variation of sorptivity with time in control and different types of calcium sources treated cement mortar specimens.

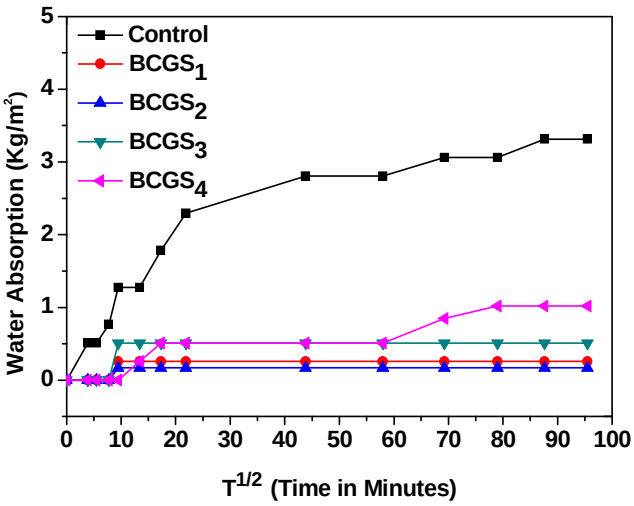
Curing	T in minutes	$t^{\wedge 0.5}$	Q in kg	Q/A kg/mm^2	k
Control	0	0	0	0	0
	15	3.873	0.001	0.51020	0.13173
	30	5.477	0.001	0.51020	0.09315
	60	7.746	0.0015	0.76531	0.09880
	90	9.487	0.0025	1.27551	0.13445
	180	13.416	0.0025	1.27551	0.09507
	300	17.320	0.0035	1.78571	0.10310
	480	21.908	0.0045	2.29592	0.10480
	1920	43.818	0.0055	2.80612	0.06404
	3360	57.966	0.0055	2.80612	0.04841
	4800	69.282	0.006	3.06122	0.04418
	6240	78.994	0.006	3.06122	0.03875
	7680	87.636	0.0065	3.31633	0.03784
	9120	95.499	0.0065	3.31633	0.03473
$BCGS_1$	0	0	0	0	0
	15	3.873	0	0	0
	30	5.477	0	0	0
	60	7.746	0	0	0
	90	9.487	0.00033	0.16837	0.01775
	180	13.416	0.00033	0.16837	0.01255
	300	17.320	0.00033	0.16837	0.00972
	480	21.908	0.00033	0.16837	0.00769
	1920	43.818	0.00033	0.16837	0.00384
	3360	57.966	0.00033	0.16837	0.00290
	4800	69.282	0.00033	0.16837	0.00243
	6240	78.994	0.00033	0.16837	0.00213
	7680	87.636	0.00033	0.16837	0.00192
	9120	95.499	0.00033	0.16837	0.00176
$BCGS_2$	0	0	0	0	0
	15	3.873	0	0	0
	30	5.477	0	0	0
	60	7.746	0	0	0
	90	9.487	0.0005	0.25510	0.02689
	180	13.416	0.0005	0.25510	0.01901
	300	17.320	0.0005	0.25510	0.01473
	480	21.908	0.0005	0.25510	0.01164
	1920	43.818	0.0005	0.25510	0.00582
	3360	57.966	0.0005	0.25510	0.00440
	4800	69.282	0.0005	0.25510	0.00368
	6240	78.994	0.0005	0.25510	0.00323
	7680	87.636	0.0005	0.25510	0.00291
	9120	95.499	0.0005	0.25510	0.00267

Curing	T in minutes	t^0.5	Q in kg	Q/A kg/mm^2	k
$BCGS_3$	0	0	0	0	0
	15	3.873	0	0	0
	30	5.477	0	0	0
	60	7.746	0	0	0
	90	9.487	0.00033	0.51020	0.05378
	180	13.416	0.00033	0.51020	0.03803
	300	17.320	0.00033	0.51020	0.02946
	480	21.908	0.00033	0.51020	0.02329
	1920	43.818	0.00033	0.51020	0.01164
	3360	57.966	0.00033	0.51020	0.00880
	4800	69.282	0.00033	0.51020	0.00736
	6240	78.994	0.00033	0.51020	0.00646
	7680	87.636	0.00033	0.51020	0.00582
	9120	95.499	0.00033	0.51020	0.00534
$BCGS_4$	0	0	0	0	0
	15	3.873	0	0	0
	30	5.477	0	0	0
	60	7.746	0	0	0
	90	9.487	0	0	0
	180	13.416	0.00050	0.25510	0.01901
	300	17.320	0.00100	0.51020	0.02946
	480	21.908	0.00100	0.51020	0.02329
	1920	43.818	0.00100	0.51020	0.01164
	3360	57.966	0.00100	0.51020	0.00880
	4800	69.282	0.00166	0.84694	0.01222
	6240	78.994	0.00200	1.02041	0.01292
	7680	87.636	0.00200	1.02041	0.01164
	9120	95.499	0.00200	1.02041	0.01069

Sorptivity Test -Coefficient of absorption

The thickness of the calcite layer on the surface of the cement mortar specimen was measured under a metallographic microscope and the thickness of film on the top surface of the cement mortar specimen was found as 90µm. The precipitation of $CaCO_3$ protective layer effect was characterized by the capillary water absorption of surface-treated cement mortar specimens and reduction in the percentage of water absorption. The effects of different curing methods by EB in various calcium sources of cement mortar specimens were compared for the percentage of reduction of the capillary water absorption. As shown in table 3, it was obvious that the capillary water absorption of the bio curing $BCGS_1$ cement mortar specimen cubes was finally reduced by 13 times in comparison with the control cement mortar specimen. This was mainly due to a denser interfacial zone formation of calcite precipitation between the cement and sand matrix by the bacteria chosen to treat the specimen. Not only could nutriment be fully supplied in the bio curing, but the amount of oxygen needed for bacterial growth was also available in the environment. Thus the micro-organisms supplied by bio curing process have good growth conditions in the micro-environment and produce some urease to hydrolyze the enzyme urea fully so that the calcite layer is finally precipitated gradually. Then the sorptivity coefficient (k), is obtained by using the expression $Q/A = k\, t^{1/2}$ where, Q - amount of water absorbed, A - cross section of the specimen that is in contact with water and t - time. The graph (figure 7) is drawn in between square root of time (x -axis) and Q/A (y-axis). Finally the k values are determined from the graph and are given in table 3. There is drastic water infiltration takes place up to 80 minutes in the control specimen as shown in figure 7. But in the EB treated $BCGS_1$ microbial cement mortar specimen shows negligible water absorption even at the initial time up to 20 minutes than the other ($BCGS_2$, $BCGS_3$, and $BCGS_4$) bio curing microbial cement mortar specimens.

Figure 7. Rate of water absorption with time in control and different types of calcium sources treated cement mortar specimen



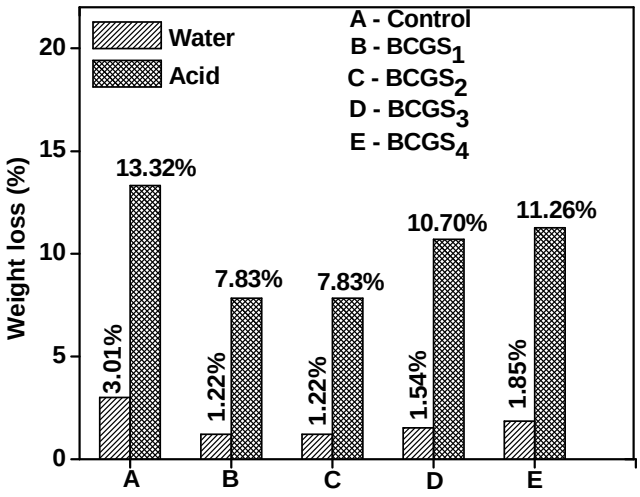
Influence of acid on microbial cement mortar specimen

After the 28 days curing process (normal and bio) the prepared cement mortar cubes in different calcium sources are weighed then submerged into the pickling solution (1:1) of water and hydrochloric acid (HCl) along with hexamine for 28 days. Then the final weight of each bio treated and control specimens are calculated and the weight loss is derived from the difference of initial and final weights, and the flow chart is drawn (figure 8) from the obtained results. The influence of acid on the microbial cement mortar specimens are compared with control specimen. From the figure 8 it can be concluded that the bio treated specimen shows less weight loss in water than the acid medium. In the water medium, the bio treated specimen has ~50% of less weight loss as compared to control specimen. In acid medium, the $BCGS_1$ and $BCGS_2$ specimen shows less (~58%) weight loss percentage while compared to $BCGS_3$ and $BCGS_4$ specimens (~82%) with control specimen. Microbially induced $CaCO_3$ precipitation in the cement mortar act as a resistive surface area to the hazardous material infiltrations and it reduce the deterioration of cement mortar surface. Hence less weight lose is observed from the microbial cement mortars compared to control.

Table 4. Mix identification and weight loss percentage of different types of calcium sources treated cement mortar specimen in acid and water medium.

S NO	Mix id	Initial Weight (grams)		Final Weight after 28 days (grams)		Loss of weight (%)	
		Water	Acid	Water	Acid	Water	Acid
1	Control	855.00	856.70	830.00	756.70	3.01	13.32
2	$BCGS_1$	826.70	826.70	816.70	766.70	1.22	7.83
3	$BCGS_2$	826.70	826.70	816.70	766.70	1.22	7.83
4	$BCGS_3$	828.60	827.50	816.00	747.50	1.54	10.70
5	$BCGS_4$	826.70	823.30	811.70	740.00	1.85	11.26

Figure 8. Weight loss percentage of different types of calcium sources treated cement mortar specimen in acid and water medium.



Conclusions

Bacterial deposition of a layer of calcite on the surface of the cement mortar specimens resulted in the enhancement of the compressive strength and decrease of capillary water uptake compared to control specimen. Thus presences of $CaCO_3$ layer prevented the penetration of water and other hazardous substance, and created a more stable and environmentally friendly situation. The present study investigated microbial methods using EB bacteria and the nutriment on the surface of the cement mortar specimens, creating a microenvironment for growth and reproduction of bacteria. Thus a calcite layer is gradually precipitated on the surface of the cement mortar specimens after 7 days which reduced its capillary water absorption in the $BCGS_1$ cement mortar specimen up to 13 times in comparison with the untreated cement mortar specimen. The results shows that it was possible to apply a bio-film ($CaCO_3$ layer) at a desired location and cracks also were cured in the existing building. From the durability studies, ie., weight loss reveals that bacterial cement mortar has less weight loss than the conventional cement mortars. Then the acid attack is also considerably reduced on the microbial cement mortar specimens. So microbial technique provides the basis for an alternative and high qualities cement mortar sealant with cost effective and eventually will enhance the durability of the building materials.

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